Current Status of
Design for FNAL-E906 Station 3 DC

Review @ FNAL

Apr. 16, 2009

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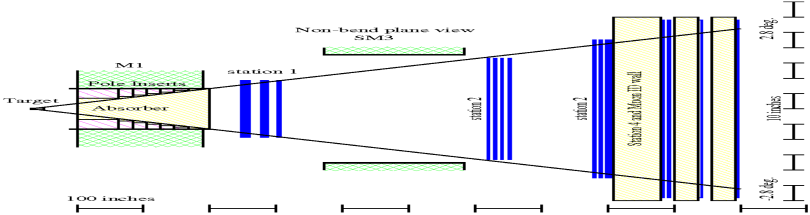
RIKEN

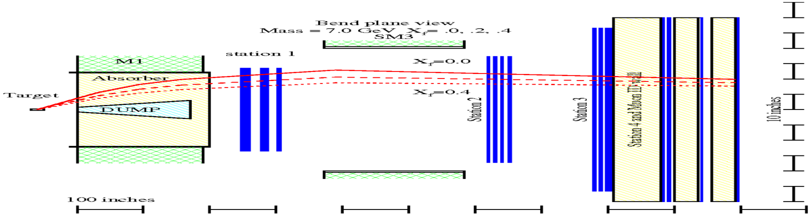
Contents

1. Introduction

1.1. Position of Station 3 Drift Chamber



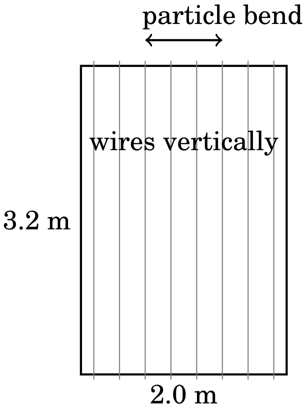
$\Uparrow$ Side view (non-bend plane) $\Downarrow$ Top view (bend plane)



- Detect $\mu^{\pm}$ with $p \gtrsim 10$ GeV/c $\Longrightarrow$Material amount doesn't matter
- 2 m width at 20 m from target $\Longrightarrow$Small incident angle, $<$10 deg.

1.2. Performance Requirement

- Detection area (initial assumption)
  - 3.2 m (vertical, y, wire length)
    ... it was chosen to match the 1st-magnet aperture
  - 2.0 m (horizontal, x)
    ... it was chosen to be more sensitive to higher x_2 based on Fast MC study
- 6 sense planes (U-U'-X-X'-V-V') with a tilted angle of $\arctan(1/4)$ = 14 deg.
- Position resolution
  - $<$400 μm per plane
  - It was chosen to be better than the muon-momentum smearing by multiple scattering at hadron absorber, and is not a tight requirement for DC
- Rate tolerance: $\sim$300 kHz per wire at maximum, depending on position



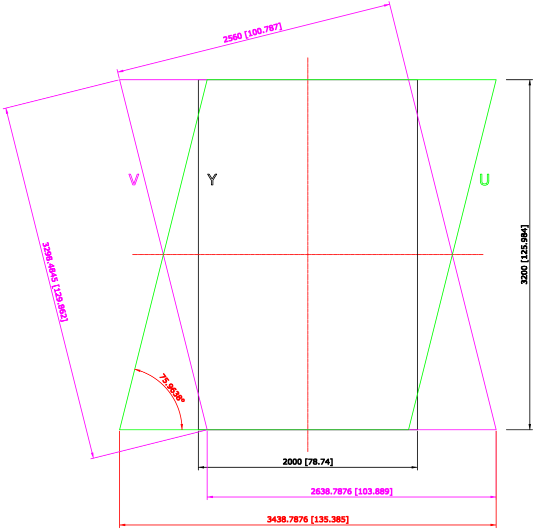
1.3. Issues that we hope to be advised at this review

- At present, two chamber configurations are under examination. Please consider and comment on both of these configurations.
  1. Using an entirely new, very large chamber
  2. Using two smaller chambers, where one can be E866 St. 2 DC.
- In order to determine the arrangement & size of chamber(s), we estimated the signal statistics from Drell-Yan process. Please consider the validity of this estimation and an allowable limit of the size
- The design of cell structure
  1. Mechanical properties
  2. Electrostatic properties
  3. Position resolution and rate tolerance
- The construction plans for the chambers
- Any other issues that the reviewers think important

2. Chamber Structure

2.1. Plans for Chamber Structure

- Frame structure (in case of 3.2 (wire) $\times$ 2.0 m size)

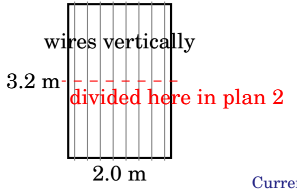


- Tilted-wire plane
  - Parallelogram shape
  - All wires have same length
  - Frame surface and wires not perpendicular
  - We hope to know the experiences on the E866 chambers (varying wire lengths and having wires non-perpendicular to a frame edge led to serious performance problems)
- U & V can be narrower than the drawing because four corners are less important

2.1. Plans for Chamber Structure

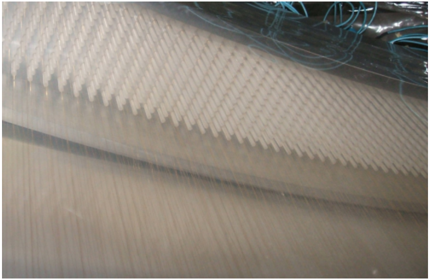
- Two plans under examination

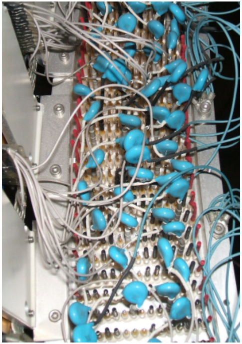
	Plan 1	Plan 2
Detection area	3.2 (wire) $\times$ 2.0 m	1.6 (wire) $\times$ 2.0 m
N of chambers	1	2 (one may be E866 St. 2)
Wiring	Feed-through	Feed-through
Frame support	Yes	Yes
Wire support	Yes	No
Cost estimate	JPY 45,000,000 (rough)	
Pros & cons	– Severe wire stability – N of readouts permissible – Large construction & transport spaces	– Geometry can become different between top & bottom – N of readouts doubles or more – Flexibility of chamber arrangement – E866 St. 2 may be reused
Issues	– Implementation of wire support	– Division arrangement – Enough readout electronics – Availability of E866 St. 2



2.1. Plans for Chamber Structure

- Adoption of feed-through method (not wire-winding method)
  - In case of 3.2 m wire length, no wire-winding machine is available in Japan and thus only the feed-through method is usable
  - Even in case of 1.6 m wire length (two divided chambers), although we have a candidate of usable wire-winding machine, the wire length is still too long and the feed-through method is better in viewpoint of all cost, time and work for construction.
  - Structure example, KEK E325 Barrel-shaped Drift Chamber
    1.4 m wire length, 2 cm cell width, 1 cm cell height, 350 μm pos. res.

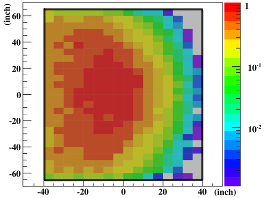




2.1. Plans for Chamber Structure

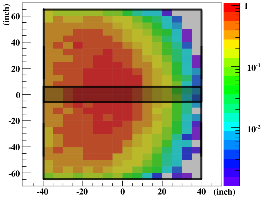
- **Chamber arrangement**
  gray box: coverage of one chamber
  colored histogram: μ^+ hit distribution at $0.35 < x_2 < 0.40$ & $x_F > 0$

- Plan 1



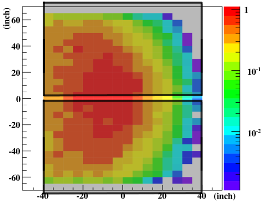
  - One chamber covers full acceptance (3.2 $\times$ 2.0 m)

- Plan 2



  - Two chambers overlap to cover full acceptance
  - Geometries are different between top &bottom

- Plan 2'



  - Gap at y=0
  - Lose stat. but greatly reduce high-rate background (fail safe)

2.2. Acceptance and Signal Statistics

- Signal statistics from Drell-Yan with various chamber sizes
  - Evaluated with Fast MC (plots are in appendix)
  - Relative statistics at $x_F > 0$

Size	x_2 0.25-0.30	0.30-0.35	0.35-0.40	0.40-0.45
128”×80” (original)	100% by definition			
with 10” gap at y=0	80%	85%	85%	85%
128”×90” (wider)	110%	107%	104%	103%
128”×70” (narrower)	80%	85%	85%	85%
118”×80” (shorter)	100%	100%	100%	100%

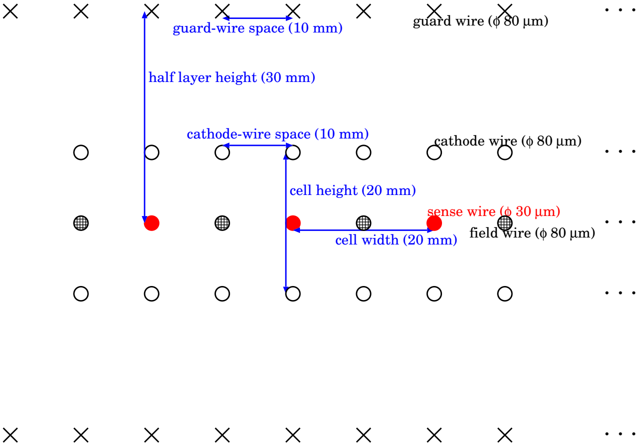
  - A chamber shorter by 10” can be used without stat. loss. Has the original study checked this aspect (or just used the 1st magnet aperture)?
  - E866 St. 2 DC is a possible backup and has
    - a 1.68 (wire) × 1.79 m size (20 cm narrower) and
    - a 1 cm sense-wire spacing.

    When it is used as one of two chambers, the stat. loss will be ∼10%
  - the 10” gap at y=0 causes 15∼20% stat. loss (and can reduce background rate to 1/3)

3. Cell Structure

3.1. Mechanical Properties

- Wire arrangement (only single layer is drawn)



  - 6 layers are stacked in one chamber (with guard wires being shared)
  - Since the required position resolution is not tight, a simple structure has been adopted for easier construction & operation

3.1. Mechanical Properties

- Reference design parameters

cell type	BOX
gas	Ar:Ethane (50:50)
cell width	20 mm
cell height	20 mm
cathode-wire spacing	10 mm
guard-wire spacing	10 mm
half layer height	30 mm
wire	sense — Au-W (Re), ϕ 30 μm
	others — Au-CuBe, ϕ 80 μm
high voltage	sense wire — 0 V
	cathode & field wires — $\sim$ -2.8 kV (common)
	guard wire — $\sim$ -0.5 kV

  - The gas is common to St. 2 & St. 3 DCs and has been almost fixed
  - HV was chosen so that gas gain is $\sim 2 \times 10^5$ with Garfield
  - Wire tensions are to be determined once the chamber design is fixed

3.1. Mechanical Properties

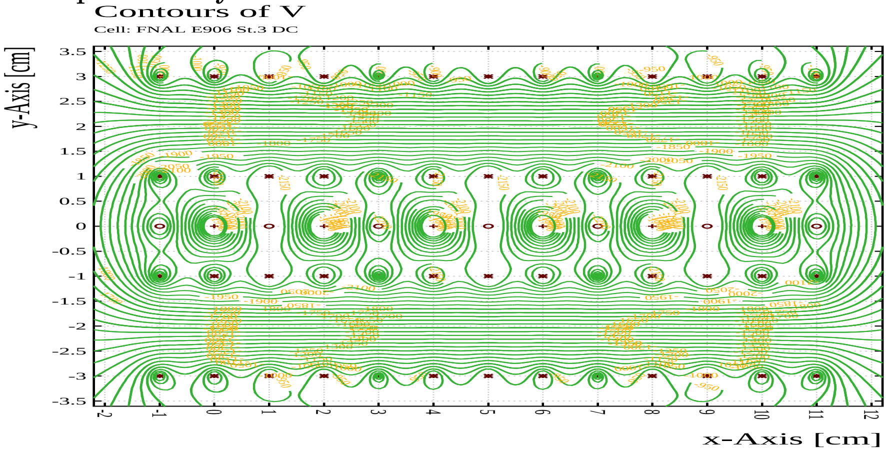
- Methods of determining parameters
  - We premised that the cathode & field HV values are common (the required position resolution is not tight and thus a simple structure is better for easier construction & operation)
  - Cell width ... It was required in order to (conservatively) tolerate background rate. On the other hand, when the number of readouts should be reduced, larger cell width can be considered
  - Cell height ... The height should be nearly equal to the width in order to achieve an enough E-field strength around sense-wire plane and a reasonable gas gain
  - Guard-wire spacing & half layer height ... The position of guard wires relative to sense wires shifts in tilted-wire planes, and this should not affect gas gain & drift line. Such stability has been confirmed with Garfield. (But also a 20 mm half layer height is stable enough. Probably we will change it in final design. *Details in appendix*)
  - Wire material & diameter ... A typical one was chosen

3.1. Mechanical Properties

- Minimum wire tensions
  - We have to confirm the minimum wire tensions before designing the chamber frame construction.
  - We have already started such study with Garfield and are going to complete it.
  - Up to now we put a higher priority on other studies like the chamber size, partly because we believe the wire tensions do not have a strict constraint (at least in plan 2) and the next cost estimate and drafting can be started even with typical values obtained from a chamber with the similar structure.
    - 80 gf on sense wires, 200 gf on other wires
    - total road $\sim$ 1 ton-force
  - In plan 1 (3.2 m wire length), because we assume to put a wire support at the center of wires, the wire length is effectively 1.6 m (same as plan 2) and thus the required wire tensions should not be much different from plan 2, although of course this plan needs a firmer check.

3.2. Electrostatic Properties

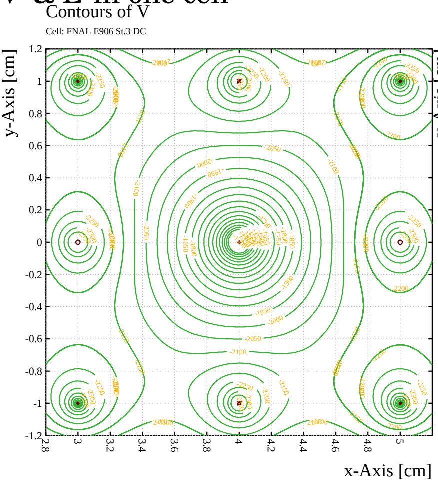
- *V* map in one layer

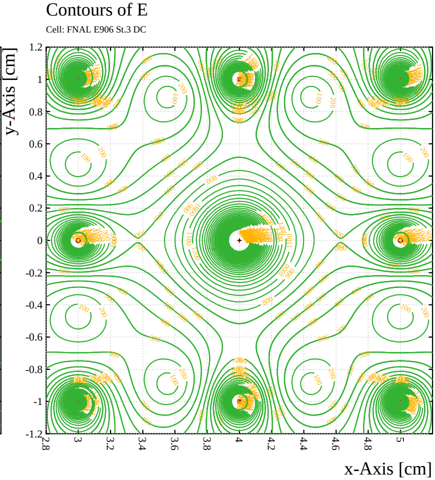


  - one small layer is simulated with Garfield
  - the 3rd-from-left cell ($x = 4$ cm) is focused on to check properties

3.2. Electrostatic Properties

- V & E in one cell



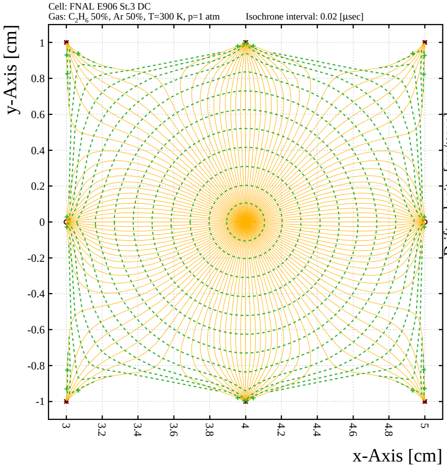


  - N of ionized e^-'s is $\sim$10 per 1 mm track path
    $\Longrightarrow$early e^-'s come from a-few-mm area around sense-wire plane
  - $E > 700$ V/cm around sense plane, drift speed saturated

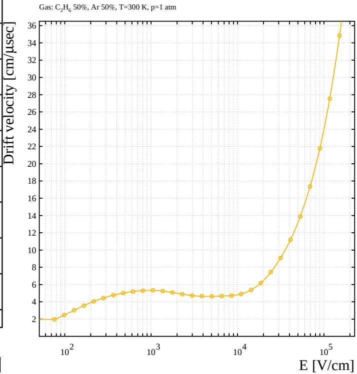
3.2. Electrostatic Properties

- Drift lines & equi-drift-time lines in one cell

Positron drift lines from a wire



Drift velocity vs E



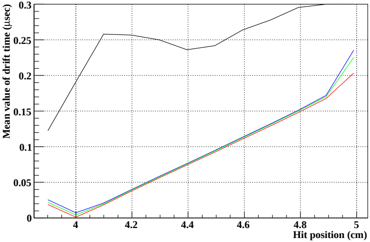
- ▷ N of ionized e^-'s is ~10 per 1 mm track path
  $\Longrightarrow$early e^-'s come from a-few-mm area around sense-wire plane
- ▷ $E > 700$ V/cm around sense plane, drift speed saturated

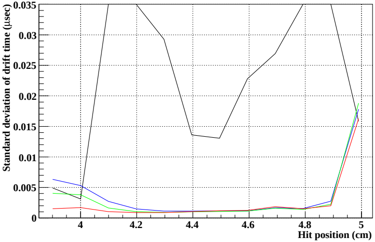
3.2. Electrostatic Properties

- Signal-Pulse Magnitude
  - Conditions & assumptions
    - Make up a signal pulse with 3 ionized e^-'s
    - Gas gain $M \sim 10^5$
    - Cell capacitance Cl = 6.3 pF/m × 3.2 m = 20 pF
    - Resistance R = 500 Ω $\Longrightarrow$readout decay time $\tau = CRl = 10$ (ns)
  - Signal-pulse magnitude
    - $V_{\text{max}} = 3Me/Cl \sim 3$ mV
    - According to signal shape in Garfield simulation, $V_{\text{peak}}/V_{\text{max}} \sim 1/8$
    - $V_{\text{peak}} \sim 300\ \mu$V
    - OK
- Tests of characteristics, like signal attenuation, pulse distortion and crosstalk, as a fucntion of wire length
  - Not yet done
  - We know a workable example for plan 2 (1.6 m wire length)

3.4. Position Resolution

- Drift-time RMS due to event-by-event fluctuation
  - Evaluated with Garfield `&DRIFT::Arrival-time-distribution`





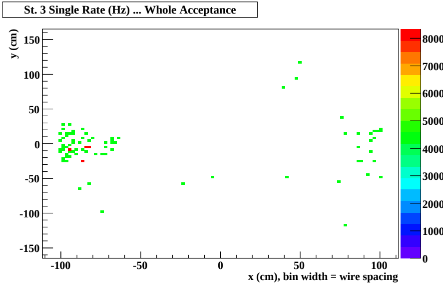
sense wire @ 4 cm, field wire @ 5 cm / line color: 1st-, 3rd-, 5th- and last-arrived e^-'s

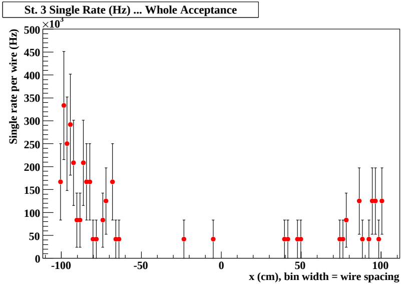
  - 2∼3 nsec $\Longleftrightarrow$100∼150 μm position ambiguity

- Well smaller than the position-resolution requirement (<400 μm per plane)
  - cf. the E866 St. 3 DC shows a similar RMS in Garfield simulation and achieved an overall position resolution of 230 μm in the experiment

3.5. Rate Tolerance

- Background-rate evaluation
  - With GEANT simulation (by Shon Watson)
  - Hit rate of $\mu^{\pm}$ from any $p+p$ interactions





  - Concentrated at the center ($y \sim 0$) of the left-side wires (mainly from $p+p \to \pi^{+} + X \to \mu^{+} + X'$)
  - At max. 5 kHz/cm^2 or
    300 kHz/wire with 2 cm wire spacing $\Longleftrightarrow$ 3 μsec hit interval

3.5. Rate Tolerance

- Rate tolerance
  - Dead time
    - Chamber memory time ∼0.7 μsec (based on Garfield, *details in appendix*)
    - No problem as the background-hit interval is 3 μsec on average
  - Decrease of gas gain (M_0) caused by residual ions around sense wire

$$M = M_0 \exp(-KM_0R)\ , \quad K = neT/4\pi^2\epsilon_0$$

$R \sim$ 1k at max.	particle flux in "counts/sec/mm-wire-length" unit
$M_0 \sim 10^5$	gas gain at $R \sim 0$
$n \sim 200$	N of primary e^--ion pairs
$T \sim 500\ \mu$sec	total ion drift time

- $\exp(-KM_0R)$

M_0		10^5	10^6	10^7
	1k	99%	95%	63%
R	10k	95%	63%	1%
	100k	63%	1%	0%

- Only 1% decrease at assumed gain ($= 10^5$), 5% decrease even at one-order-higher gain or rate

3.5. Rate Tolerance

- Capability of Widening Cell
  - Cell structure tested
    - 3 cm width, 2 cm height (widened by 1 cm)
    - -3000 V on cathode & field wires, gain 2×10^5
  - Garfield simulations & calculations (*plots in appendix*)
    - Position resolution & rate tolerance ... OK
    - Drift-speed stability ... not saturated around sense plane ($E < 500$ V/cm)
  - Only the low E field is problematic, but different HV values on cathode & field wires can solve this. Therefore we conclude that we can widen the cell when the number of readouts must be reduced to match the number of available readout electronics

4. Construction Schedule

- Time schedule

2009.	04	Drafting and cost estimation start (by REPIC)
	05	Design determined
	06	Material prepared
	late summer	Construction start @ RIKEN
2010.	02	Construction completed (*tentative below here*)
	03	Test @ Japan
	04	Transport to FNAL & test
	06	Beam exp. start

  - The design will be determined in May on the basis of funds we earned
  - If we use two divided chambers, the time when each chamber is constructed should be also considered (at once or one-by-one)
- Fund
  - We had submitted several budget requests to Grant-in-Aid for scientific research
  - At early April, our second largest budget request was approved
  - At mid May, we will know whether our largest budget request is approved

5. Summary — I

- We are going to finalize the chamber design at late May after we know whether our largest budget request is approved
- The current design has been presented. We hope to be advised on each detail;
  - Chamber structure
    - Do you agree that we construct the chamber with the feed-through method?
    - What are the difficulties on the current frame structure (due to the non-perpendicularity between frame surface and wires, etc.)
    - Is there any other pros or cons for plan 1 & 2?
    - Do you have a preference on these plans?
  - (continue...)

5. Summary — II

- Cell structure
  - Are there any better cell structure or parameters?
  - Do the E field & the drift line of the cell have any problems?
  - Is the estimation of signal-pulse magnitude reasonable?
  - Is the estimation of position resolution with Garfield reasonable?
  - Is the estimation of rate tolerance reasonable?
  - Is it a fair conclusion that we can widen the cell (at least) up to 3 cm by adjusting HV values?
- Other issue
  - Does our construction schedule match the collaboration-wide schedule?
  - Are the estimations of signal statistics expected when the acceptance is changed reasonable? Particularly has the original study checked whether a 10” shorter chamber (3.2 m $\rightarrow$ 3.0 m) causes no stat. loss?
  - What is an allowable limit of the chamber size or the gap at y=0 in viewpoint of statistics? Particularly how is the use of E866 St. 2 DC?
  - How serious is the increase of the number of St. 3 readouts in viewpoint of DAQ system?

6. Appendix

Contents of Appendix

- Guard-Wire Spacing & Guard-Wire-Plane Spacing
- Chamber Memory Time
- Capability of Widening Cell
- Signal Statistics — x_2 vs x_1
- Signal Statistics — x_1 Dist. at x_2 Bins
- Signal Hit Distributions (Diff. x_2 Bins)
- Chamber Size & Division (= Acceptance)

Guard-Wire Spacing & Guard-Wire-Plane Spacing

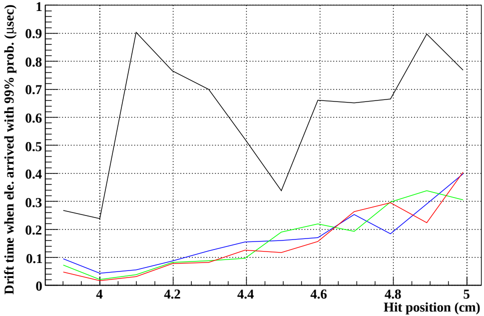
- Criterion
  - In tilted-wire planes, the position of guard wires relative to sense wires shifts
  - Guard-wire positions should not affect gas gain & drift line
  - In Garfield (only in 2-dim.), guard-wire positions are moved with 1 or 2 mm step and the deviations of gas gain & drift line are checked
- Garfield setting
  - 10 cells/layer $\times$ 2 layers (like X & X')
  - focus on one cell at the center of one layer
  - -2.8 kV on cathode/field wires, -1 kV on guard wires
- Results

GW spacing	GWP spacing	Gain	Gain deviation
1 cm	6 cm	3.9e5	$<0.1\%$
1 cm	4 cm	1.8e5	$\sim0.1\%$
2 cm	4 cm	4.2e5	$\sim0.5\%$

  - Drift lines unchanged around sense-wire plane in all 3 settings

Chamber Memory Time

- Evaluated with Garfield
  `&DRIFT::Arrival-time-distribution`
  - The time when a last electron in each event arrives at sense wire with 99% probability



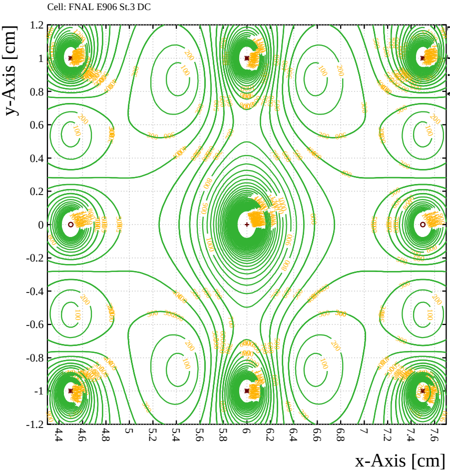
  - last electron drawn as black line, $\sim 0.7\ \mu$sec
- cf. this method shows that the E866 St. 3 DC has a $0.3 \sim 0.5\ \mu$sec memory time

Capability of Widening Cell — I

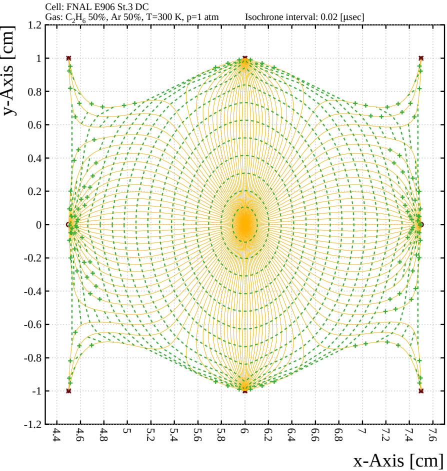
- Cell structure tested
  - 3 cm width, 2 cm height (widened by 1 cm)
  - -3000 V (cathode & field wires), gain 2×10^5
- Results
  - Garfield (plots in next slides)
    - Position resolution ... 2$\sim$3 nsec
    - Chamber memory time ... 0.7$\sim$1.0 μsec
    - Drift-speed stability ... not saturated around sense-wire plane ($E < 500$ V/cm)
  - Rate tolerance
    - Single rate: just $\times$1.5 of the rate with 2 cm width
      $\Longrightarrow$8 kHz/cm^2 or 450 kHz/wire (2 μsec single interval)
    - Gas gain: 98% at R = 1.5k (expected rate),
      89% at R = 15k, 32% at R = 150k
- Only the low E field is problematic, but different HV values on cathode & field wires should can this

Capability of Widening Cell — II

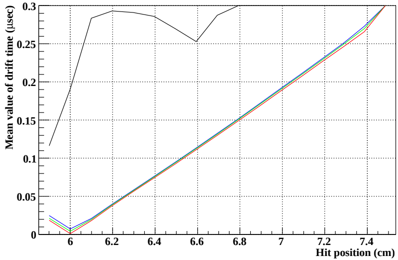
Contours of E

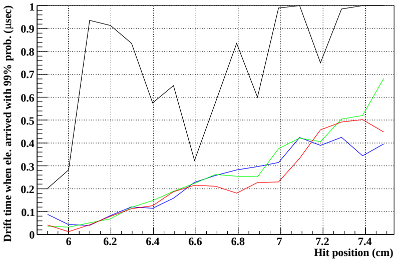


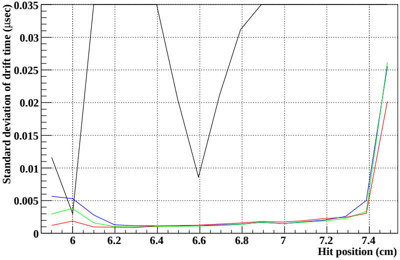
Positron drift lines from a wire



Capability of Widening Cell — III



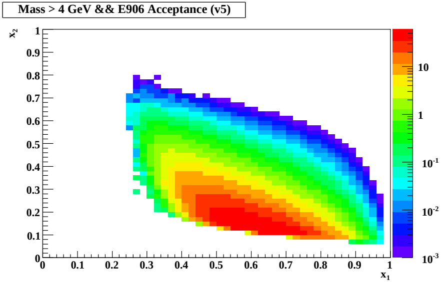




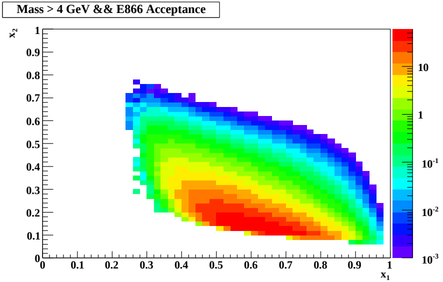
Signal Statistics — x_2 vs x_1

- In order to determine the arrangement & size of chamber(s), we estimated the signal statistics expected when the acceptance is changed in some ways.
  - E906 original ... 128”×80”
  - 10” gap at y=0 ... 128”×80” with gap
  - 10” narrower ... 128”×70”
  - 10” shorter ... 118”×80”
  - E866 DCs ... 104”×92” at St. 3 & 66”×70” at St. 2

E906 original

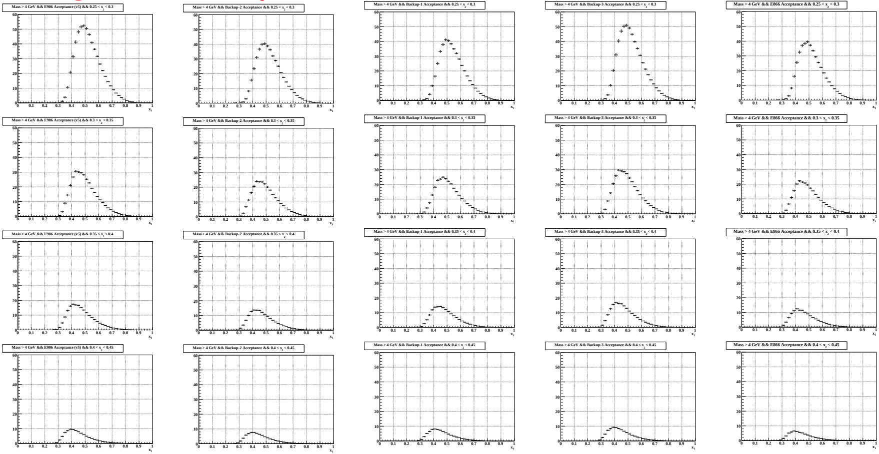


E866 DCs



Signal Statistics — x_1 Dist. at x_2 Bins

E906 original | 10” gap at y=0 | 10” narrower | 10” shorter | E866 DCs



From top to bottom,

$0.25 < x_2 < 0.30$, $0.30 < x_2 < 0.35$, $0.35 < x_2 < 0.40$ and $0.40 < x_2 < 0.45$

Signal Hit Distributions (Diff. x_2 Bins)

- Evaluated with Fast MC
- μ^+ hit distributions in next slide
- Left-right reversal in case of μ^- hit
- Observations
  - A wider chamber can increase the statistics particularly at low x_2 (as Paul Reimer reported)
  - Top-bottom edges are less important (the current size has been determined so that it matches the magnet aperture)

Signal Hit Distributions (Diff. x_2 Bins)